OTS: 60-41,053

JPRS: 5160

28 July 1960

HIGH-POWER HIGH-FREQUENCY TEST STAND VIU-I MAI-VIAM FOR TESTING THE ENDURANCE AND VIBRATION STRENGTH OF PARTS AND UNITS OF JET ENGINES AND AVIATION MATERIALS

- USSR -

by A. M. Sulima, M. I. Yevstigneyev
V. M. Trusov

Distributed by:

OFFICE OF TECHNICAL SERVICES
U. S. DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.

Price: $0.50

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
205 EAST 42nd STREET, SUITE 300
NEW YORK 17, N. Y.

JPRS: 5160
CSO: 4253-N

HIGH-POWER HIGH-FREQUENCY TEST STAND VIU-I MAI-VIAM (VIBRATION TEST STAND 1 OF THE MOSCOW AVIATION INSTITUTE AND THE ALL-UNION INSTITUTE OF AVIATION MATERIALS) FOR TESTING THE ENDURANCE AND VIBRATION STRENGTH OF PARTS AND UNITS OF JET ENGINES AND AVIATION MATERIALS

/ This is a translation of an article written by A. M. Sulima, M. I. Yevstigneyev and V. M. Trusov in Nauchnyye Doklady Vysshey Shkoly, Mashinostroyeniye i Priborostroyeniye (Reports of School of Higher Learning, Construction of Machines and Apparatus), No. 2, Moscow 1959, pages 110-119./

The problem of the fatigue strength of metals has a special bearing on the development of modern aircraft engine design. The parts of these engines work under enhanced loads and high-temperature conditions. Gas-turbine blades in jet engines are subject to particular strain and their endurance largely determines the life of standard-type jet engines. Operating experience shows that premature breakdown of turbine blades is traceable to fatigue in most cases.

A substantial drawback of present-day technological testing of heat-resistant materials resides in the fact that the conventional fatigue-testing machines of the OZIP, II - 391 and other types presently applied are low-speed machines which do not permit of performing endurance tests for alloys at high frequencies; the maximum frequency attainable ranges between 50 and 200 cps, whereas the gas-turbine blades of jet engines are operating at higher frequencies. Notably, the frequency of bending vibrations of the blades reaches 800 - 1000 cps on the 1st tone and 3000 - 3.500 cps on the 2nd tone; failure occurs mostly under conditions of resonance vibrations involving frequencies of an order above the 1st-tone level. There have been cases of blade failure on levels as low as the 48th harmonic. For this reason, a satisfactory solution of the problem of prolonging the life of existing and newly designed aircraft engines rests on the necessity of conducting fatigue tests for blades and blade materials at high-frequency loads and creating high-frequency test

equipment. The high-power vibration test stand VIU - 1 MAI - VIAM, designed on orders from the aircraft industry at the Chair "Aircraft Engine Production" at the Moscow Order of Lenin Aviation Institute im. S. Ordzhonikidze permits of conducting fatigue tests for specimens of heat resistant materials at high tem peratures in a wide range of controllable frequencies (50 to 3000 cps) as well as tests on actual gas-turbine blades in a regime approaching service conditions in an operating engine. The putting into service of this test stand is of vital consequence to the aircraft industry in the study and technological research of new kinds of blade materials. On this stand, it is also possible to test the vibration strength of cermets and diffusion coatings, welded and soldered junctions, the effectiveness of age-hardening techniques, the influence of the shape factor and other geometric parameters of the product on its endurance, etc.

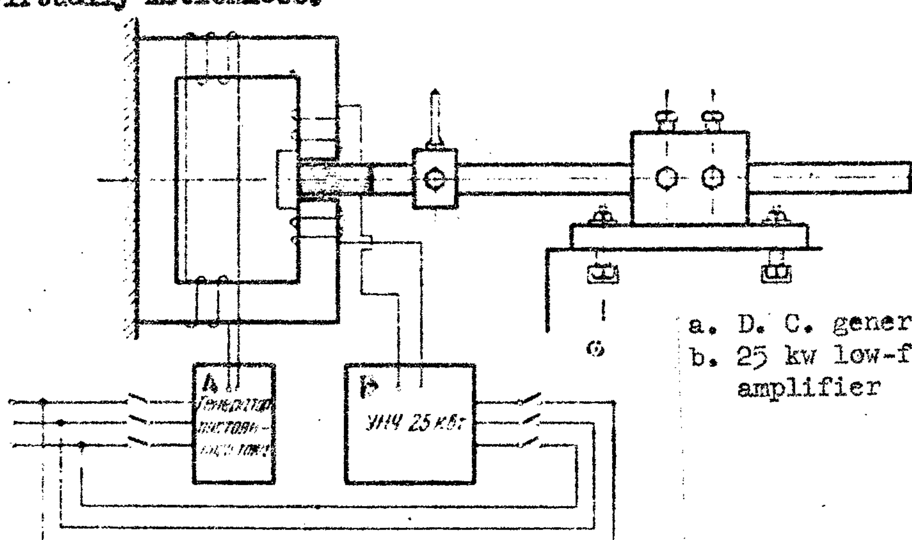
Design of the High-Frequency Vibration Test Stand VIU-1 MAI - VIAM

This test stand represents a high-power testing machine of the resonance type. Its vibration excitation system consists of a powerful electronic amplifier and an electromagnetic converter. * The stand is operable in conditions of self-excitation and by independent excitation. To enable its being operated the latter way, the vibration stand is equipped with a SG - 12 sound generator which transmits pulses directly to a powerful amplifier. In conditions of natural oscillation the stand operates on the principle of a pitch auto-generator as is applied in radiotechnics for

* I. I. Panchenko, "Method of Exciting Vibrations in Turbine Blades for Fatigue Tests", candidate's thesis, 1954. Central Technical Design Institute im. Polzunov.

frequency stabilization; in the natural oscillation system of the test stand the pitch is set by the specimen itself. The principle of operation of the stand is clearly seen from the subjoined schematic diagram (Fig. 1).

The specimen (or blade) to be tested is attached to a bracket beam by means of a special holder. The free end of the beam is placed between the poles of a powerful electromagnet. The poles are provided with induction coils connected to a high-power amplifier. In passing through the induction coils the a.c. adjusted to the sound frequency creates periodic electromagnetic attractive forces causing vibrations in the beam which are transmitted to the test specimen. In the case of resonance frequency vibration, that is, whenever the frequency of the perturbing force of the magnetic field acting upon the beam coincides with the natural-oscillation frequency of the specimen, latter's vibration amplitude is at its maximum, while that of the beam is bound to be very low, i.e. the beam is virtually motionless.



a. D. C. generator
b. 25 kw low-frequency amplifier

Simplified schematic view of the VIU-1 test stand

Thus, in this vibration system the test specimen functions as dynamic absorber of the energy of the forced vibrations of the beam which, in its turn, acts merely as transmitter of the oscillation energy from the magnetic field to the specimen. The frequency of the perturbing force acting upon the system beam-specimen may be set either by the sound generator (SG-12)- in the case of independent excitation - or by the test specimen itself via the transmitter, acting on the principle of self-excitation. In the latter case, a closed vibration system specimen — transmitter — a.c. magnetic field — beam— specimen is created, in which the test stand operates under conditons of natural vibration.

Optimum Parameters of a Natural-Vibration System of Operation of the Test Stand

The optimum parameters of a natural-vibration regime of operation of the test stand may be determined by reference to the elementary schema of the autogenerator. This operational regime may be represented by an equivalent oscillatory anode circuit with the following elements connected in series: C_e— capacitance, L_e— inductance, and R_e— active resistance ($L_e C_e R_e$) where L_e and C_e determine the resonance angular frequency ω_r, and R_e characterizes the energy losses (by internal friction, radiation, etc.)* When closing this circuit by a feedback element having a transmission factor K_f, we obtain a sound frequency autogenerator, a simplified schematic view of which is shown in Fig. 2.

* ————————

I. S. Gonorovskiy, Fundamentals of Radio Engineering, Moscow, 1957

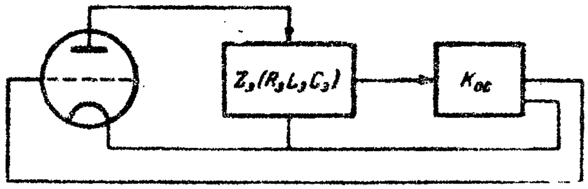


Fig. 2. Simplified schematic view of a sound frequency autogenerator

The parameters of the optimum operating conditions of the vibration test stand are determined from an anlysis of the equilibrium equation for the given autogenerator, which may be written in the general form as follows:

$$|\vec{S}_{cp}| \cdot |z_{э}(j\omega_p)| \cdot |K_{oc}(j\omega_p)| \, l^{j(\pi+\varphi_z+\varphi_{oc})} = 1, \qquad (1)$$

where S_m is the mean transconductance of the tube;

Z_e is the impedance of the equivalent anode circuit;

K_f is the feedback factor;

φ_z, φ_f are arguments of the mean transconductance of the equivalent oscillatory anode circuit and of the transmission factor of the feedback circuit K_f ($j\omega$);

ω_r is the resonance angular frequency of the equivalent oscillatory circuit.

From this equation we may deduce the following two conditions of optimum operation.

1) the product of the moduli of the quantities $\vec{S}_m$, Z_e ($j\,\omega_r$)

and $K_f(j\omega)$ must be equal to unity:

$$S_{cp} \cdot Z_э \cdot K_{oc} = 1. \qquad (2)$$

2) The sum of the phase shifts in the closed circuit of the autogenerator must be equal to the integer 2π:

$$\pi + \varphi_э + \varphi_{oc} = 2\pi n. \qquad (3)$$

i. e.,

$$\Sigma\varphi_i = 2\pi n,$$

where n is zero or any integral number.

The first condition is easy to comply with by way of altering the amplification factor of the amplifier. The second condition can only be satisfied provided the phase equilibrium in the closed autogenerator circuit is maintained. The combined frequency-phase characteristic of the amplifier of the equivalent plate load and the feedback circuit depends on the frequency of the oscillation circuit $\varphi_\Sigma = f(\omega)$ and may be

where ψ_φ is the additional phase shift in the closed circuit of the autogenerator, corresponding to the optimum conditions of operation of the test stand at a preset vibration frequency. [illegible]

[illegible] equilibrium

where ψ_φ is the additional phase shift in the closed circuit of the autogenerator, corresponding to the optimum conditions of operation of the test stand at a preset vibration frequency. [illegible]

The problem of selecting the system of excitation of the vibrations and stabilizing the operating conditions for their generation was approached from the angle of radio en/gineering. This has resulted in a vibration test stand of novel design and of a quality that surpasses the one of a similar type designed by the Central Technical Design Institute im. Polmunova. The application of the principle of a pitch autogenerator, on which the excitation schema of the VIU - I MAI - VIAM is based required design features and the creation of new block diagrams which were lacking in setups of similar type described in the literature.

Block Diagram and Structural Features of Basic Units of the Test Stand

Following are the basic units of the vibration test stand (see Fig.3):

1. Excitation unit (pulse generator)
2. Phase rotator
3. Amplifier - limiter
4. Power amplifier
5. Electromagnetic converter
6. Feeding source and CBS (Controlling, Blocking and Signalling) system
7. Measuring apparatus.

The excitation unit is fitted to operate on two systems: a) for independent excitation, using the SG-12 sound generator which transmits oscillatory pulses directly to the high-power amplifier (for resonance vibration, the machine is tuned by manual frequency-variation of the pulse generator) ; b) in the natural-oscillation system, the pulse transmitting element is the test specimen itself which is electrically connected

to the amplifier through the transmitter. The mechanical vibrations of the specimen are transformed by the pulse transmitter into electric oscillations which, in turn, are transmitted to the phase rotator. The latter ensures the necessary conditions for self-excitation of the generator and the optimum natural-oscillation pattern that suits the maximum efficiency of the installation. From the phase rotator the pulse is transmitted to the amplifier-limiter and, thereafter to the power amplifier. The amplifier-limiter of the standard type TU - 5 - 3 serves as stabilizer of the input voltage which maintains the constancy of excitation of the high-power amplifier following next.

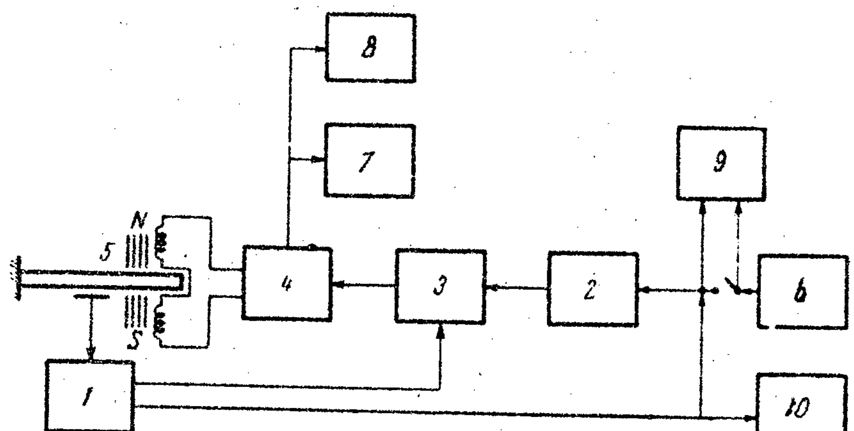


Fig. 3. Block diagram of vibration test stand VIU - I

1 - excitation unit; 2 - phase rotator; 3 - amplifier-limiter; 4 - power amplifier; 5 - electromagnetic converter; 6 - sound generator; 7 - cycle counter; 8 - frequency meter; 9 - electronic indicator of specimen failure; 10 - measuring device for vibration amplitude of

pecimen.

Thence the amplified oscillations pass to the electromagnetic converter and are converted to mechanical vibrations of the beam-specimen ystem.

The power amplifier represents the most important unit in the setup. he quality of its design is determinative for the stability of operation f the test stand as a whole. The amplifier is built as a four-stage ush-pull circuit system on powerful tubes with high-voltage B-supply. he first stage comprises two 6 PZS (beam tetrode) tubes; the second preliminary) stage operates on two GM - 60 tubes, impedance-coupled n the anode circuit, the third (pre-output stage) on four GM-100 type ubes, and the fourth (output stage) on two water-cooled G-452 tubes. he output stage is equipped with a powerful OMA-210/35 transformer with high-inductance primary coil ensuring satisfactory frequency response f the amplifying channel and quite insignificant nonlinear distortions n the high-frequency range.

A high-power rectifier, built on the pattern devised by Laryonov n six phanotrons of the type VG - 237, is used for B-supply of the mplifier tubes. The phanotron heaters are fed from six separate transormers, while the anode current is supplied from a ZTM - 75/10 transormer. Connected to the plate circuit of the output stage of the amplifier are relays of minimum protection which operate to switch off the est stand in case of breakdown of any of the tubes. To stabilize operation of the amplifier, the wiring diagram provides for high- and

low-frequency limiters and other supplemental units which permit of far-reaching adjustment of the current flow in the circuit, little dependent on frequency. Thorough shielding of all amplifier stages ensures reliable protection from the influence of fields generated by the various units within the whole system of the high-power amplifier. The latter is mounted on a separate metal frame representing an open, rigid welded structure. The entire circuit of the high-power amplifier is supplied with three-phase 50 cps 220 v alternating current from the mains; the full output voltage is 240 v. The frequency band reproduced by the amplifier lies in the range of from 50 to 10,000 cps. The rated output power of the amplifier at an effective output level of 240 v and a load of 2 to 3 ohms amounts to approximately 30 kw.

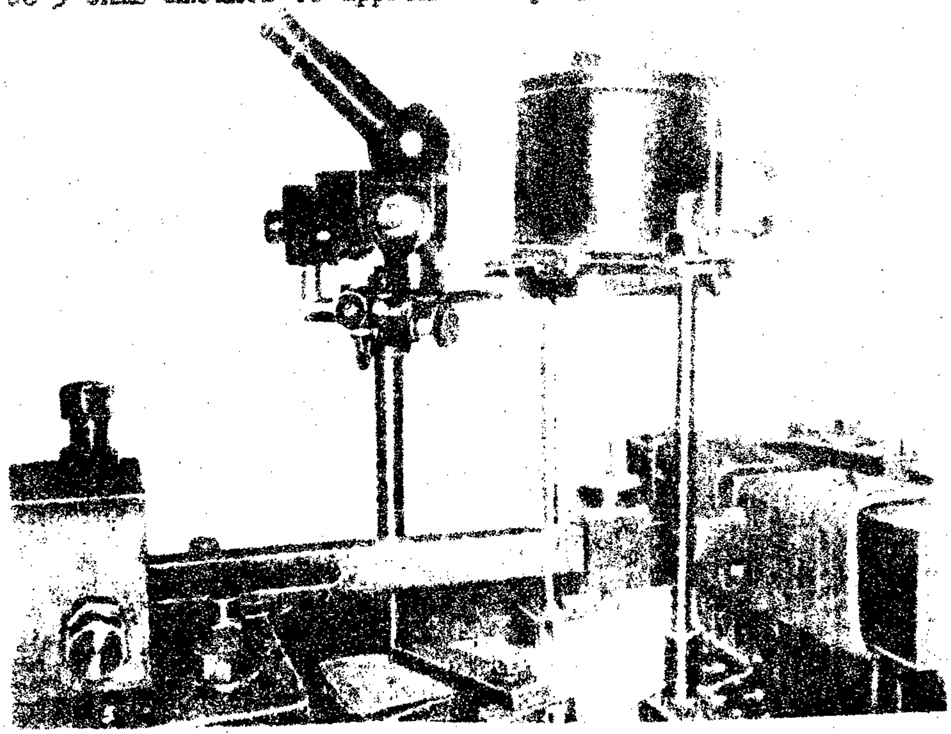


Fig. 4. General view of magnetic converter
1- Electromagnet; 2- induction coils; 3 - beam; 4 - support; 5 - vibrating table; 6 - test specimen; 7 - holder; 8 - high-temperature furnace; 7 - microscope

Converter

The vibration test stand VIU - I MAI- VIAM is equipped with converters of the following three types for converting the eletric power to mechanical vibration energy in the test specimen:

1. An electromagnetic converter for testing specimens in the frequency range of 100 - 3000 cps;

2. An electrodynamic converter for tests at frequencies ranging from 1000 to 5000 cps; and

3. A magnetostrictive converter for frequencies between 5000 and 15, 000 cps.

The electromagnetic converter (Fig. 4) consists of an electromagnet 1, induction coils 2 and a steel beam 3 having a cross section of 45 by 45 mm. The electromagnet together with the voice coils is mounted on a carriage which by means of a worm gear is fitted to travel horizontally along the directional grooves provided in the supporting plate. A general view of the magnetic converter is presented in Fig.4. Two types of electrodynamic converters are uses, viz., with a short - circuited coil and with a movable SKBIM voice coil. The magnetostrictive converter is in the blueprint stage.

General Wiring Diagram and CBS (Control, Blocking and Signaling System)

All units of the vibration stand are located in a separate room and have been designed for convenient servicing. The high-voltage oil transformers OMA 210/35 and ZTM - 75/10 are placed in an insulated compart-

ment. The transformers are connected with the high-power amplifier by means of busbars mounted along the wall on high-voltage insulators with protective grounding. The power cable and the high-voltage wiring connecting the different units are laid out in closed trenches. High-power KT -23 A type cont actors, mounted on a separate power panel, are applied for feeding the stand from the mains. The control switches and regulating instruments are arranged on a special shielded control desk which also serves as a bulkhead separating the high-power amplifier unit from the converter and the vibration stand proper. Access to the compartment accommodating the high-power amplifier is by an electrically blocked ed one-leaf metal door provided with a protective relay system.

Measuring Devices

A stereoscopic MBS - 2 microscope is used for measuring the vibration amplitudes of the test specimen. The microscope gives an erect three-dimensional image and 3.5 to 119 power at a field of vision of 39 ÷ 1.9 mm and a constant focal length of 64 mm for all magnifications.

The operating frequency is measured with an ICh - 6 generator-type electronic frequency meter with an accuracy to within 1.5 % in the range of 100 to 20,000 cps.

A radiometer of the type PS - 10,000 (Flecks) is utilized for counting the number of cycles up to failure of the speciment. The instrument consists of separate counting units covering a range of up to 10^9 cycles (with an accuracy of 1 cycle).

High-temperature tests are performed with the aid of a special ce-

ramic electric furnace. This shaft-type furnace is designed on the graded-resistance pattern, which ensures the necessary uniformity of temperature distribution in the zone of location of the test specimen. Spiral coils of 5 mm - wire made of an EI - 626 alloy serve as heaters. A maximum effective temperature of 1000° C is attained. The furnace is installed on the vibrating table by means of a special frame, along which it is allowed to travel in a horizontal direction parallel to the vibrating beam, being fastened in the desired position relative to the test specimen. The heating furnace, which is fed from a separate power panel, is switched into action by means of two type P-413 welded magnetic starters controlled by a 3-position electric regulator representing a relay-type block with a system of blocking contacts and a manipulator. Adjustment of the set temperature regime of the furnace is by automatic control.

The temperature of the specimen is maintained automatically and is measured from the readings of measuring thermocouples adjusted in the heating chamber of the furnace near the surface of the specimen (at a distance of 4mm). The temperature is controlled and automatically adjusted from an independent control desk equipped with two EPP-06 potentiometers as well as blocking and signaling devices. A constant temperature in the cold thermocouple junction is maintained by means of a type TSKh thermostat connected to the control panel through a 220/85 reducing transformer. With the aid of automatic thermoregulation the temperature level in the furnace is maintained to within $\pm$ 1%.

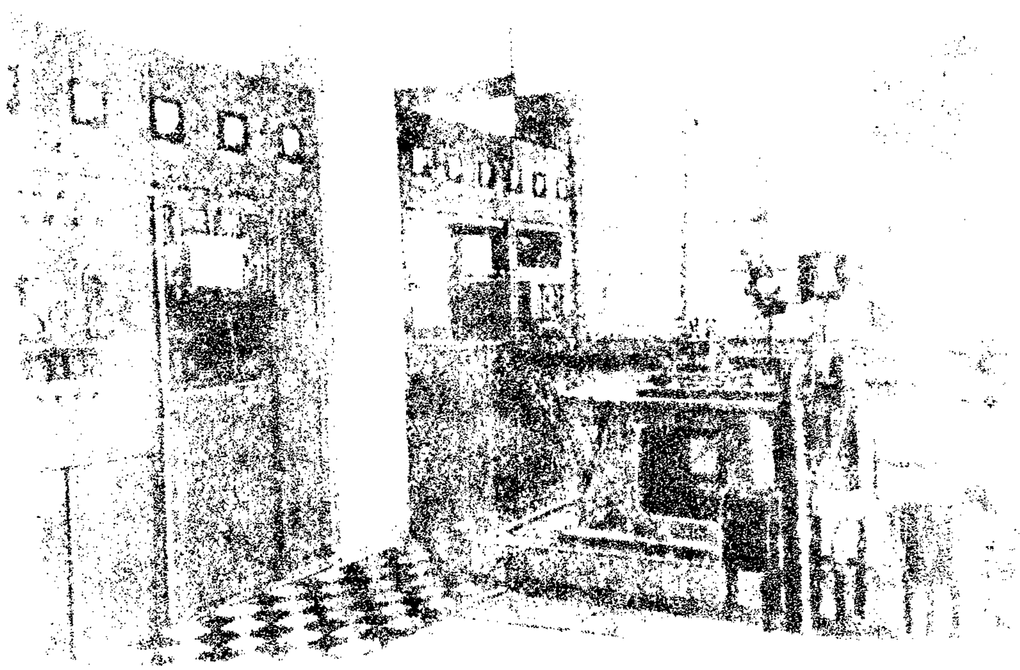


Fig. 5. General view of VIU - 1 MAI-VIAM test stand

Testing Procedure

For fatigue testing of heat-resistant materials there are used cantilever specimens of circular or rectangular cross section. The length of the specimens is established by calculation depending on the preset frequency from the Formula

$$l = \sqrt{\frac{\alpha}{2\pi f} \cdot \sqrt{\frac{EJ}{m}}} \qquad (6)$$

where l is the calculated length of the specimen in mm;

α is the root of the equation for the inflective form of the beam vibration;

f is the test frequency, vib/sec;

E is the modulus of elasticity in kg/mm^2;

J is the moment of inertia in mm^4;

m is the mass per unit length in $kg/sec^2/mm^2$;

The test specimen is clamped in the holder and is adjusted on the beam in a resonance position. Switching on the vibration stand and bringing it up to the operating vibration range at a preset frequency and amplitude is carried out according to service instructions. Operating conditions for the installation are established under the testing program and kept constant for the entire duration of the tests up to the moment of failure of the specimen. Control over the stability of operating conditions is achieved by constant observation of dials and the readings of automatic devices recording the temperature and vibration frequency of the specimen. In the tests, the specimens are brought up to failure. Their vibration amplitude is kept stable over the whole duration of the test up to failure point.

The magnitude of the vibration amplitude is determined with the MBS-2 microscope from the widening of a notch made at one end of the specimen. An accuracy of $\pm$ 5 μ in amplitude measurement is assured. The number of cycles recorded up to the instant of failure is read from the dial of the PS - 10,000 electronic counter. The stress in the zone of failure of the specimen is determined from the Formula

$$\sigma = \frac{3,52Ed}{2l^2} \cdot A \text{ kg/cm}^2 \qquad (7)$$

where A is the vibration amplitude at the peak of the specimen in mm;

l is the calculated length of the specimen in mm;

E is the modulus of elasticity in kg/mm^2;

d is the diameter of the specimen in mm .

Stress measuring prodedures for test specimens also provide for the application of wire resistors, apart from the optical method.

The manufacture of wire resistors and the preparation of specimens for tensometric measurement is subject to special procedures.

Operating Characteristics of Vibration Test Stand VIU - I MAI - VIAM

The vibration test stand was put into operation in March 1958 and has since been used for fatigue testing of various materials. From the startup, it has been in operation for 1000 hours of machine time without needing repair. Throughout the period of actual service and trial runs at different loads the machine revealed a high degree of stability and dependablility of all its units. The automatic equipment and the system of electric and mechanical blocking operate satisfactorily and possess the nesessary protective properties.

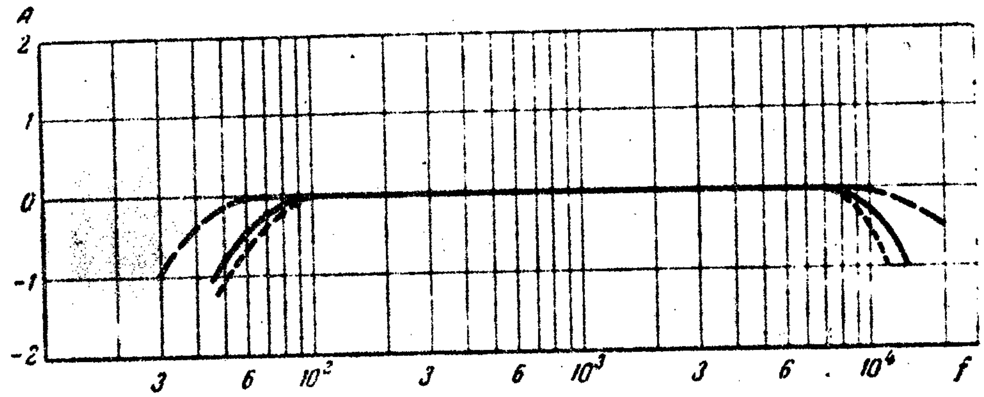


Fig. 6. Diagram showing the frequency characteristics of the installation 1 - output amplifier; 2 - amplifier-limiter; 3 - entire amplifier circuit

Before starting the programmed tests, the frequency and amplitude characteristics of the amplifier were taken. The data obtained are plotted in Figs. 6 and 7. It is seen that in the preset frequency range these characteristics do not show large distortions under load and that all measurement units work with due stability. The output power of the amplifier circuit reaches about 30 kw, which permits of testing for fatigue and vibration not only specimens, but also large-size turbine blades. The excitation method applied on this test stand makes it possible to generate strong vibrations in the specimens and blades tested and to bring them up to failure due to fatigue.

* * *

The high-power high-frequency vibration test stand VIU - I MAI-VIAM has shown a high measure of dependability in operation and stability of

preset testing conditions. On this test stand it is possible to perform fatigue tests of specimens and parts made of both magnetic and non-magnetic materials in a wide range of controllable frequencies (50 to 3000 cps). The machine is equipped with high-temperature furnaces with automatic thermoregulation and precise apparatus for measuring vibration frequencies and amplitudes with electronic counters and other devices. The tests conducted on the VIU - I MAI-VIAM on heat-resistant alloys

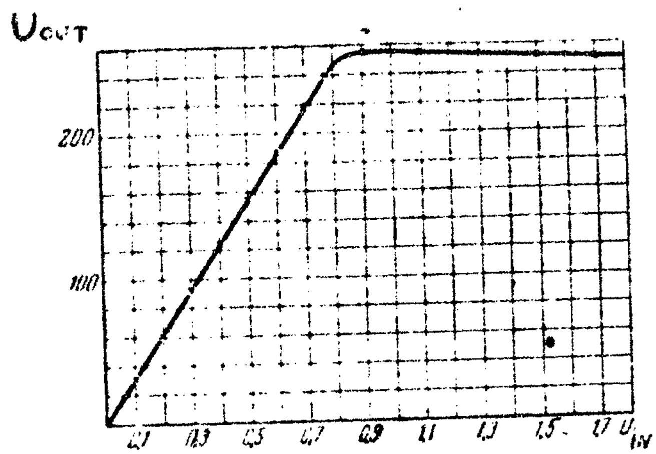


Fig. 7. Graph showing characteristics of entire amplifyer circuit

make the closest possible approach to reality in simulating their service in actual engine operation, using only a fraction of the time required to obtain a fatigue curve on conventional fatigue-testing machines. This is of eminent importance for the creation of new kinds of heat-resistant materials and for obtaining final data for the Special Design Bureau in projecting turbine blades and compressors operating at high frequencies.

This paper has been presented by the Chair of "Aircraft Engine Production" at the Moscow Aviation Institute im. S. Ordjonikidze

Received by the Editors on March 10, 1959

2175

END